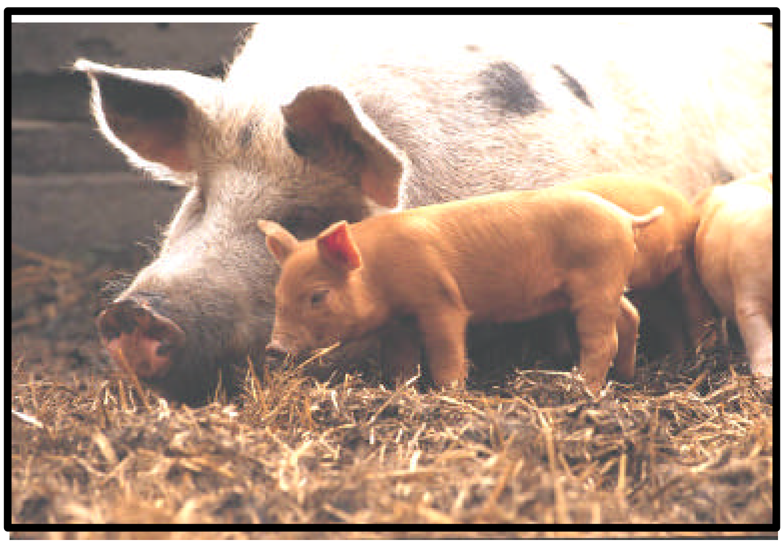
Bureau of Water

South Carolina Department of Health and Environmental Control

Alternative Technology for the Treatment and Handling of Swine Manure

Report Presented to the SC DHEC Board on
August 9, 2001



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Introduction

In 1964, the South Carolina Agricultural Statistics Service reported that South Carolina had approximately 8.1 million acres in farmland. By 1997, the South Carolina Agricultural Statistics Service reported this number had dropped to approximately 4.6 million acres. According to these statistics for this time period, South Carolina is losing farmland on the average of approximately 100,000 acres per year. Two reasons for this decline are the movement of urban areas into traditional agricultural and rural areas and the decline of farm profits. As farm profits decline, farmers are forced to become larger and more specialized to maintain an adequate standard of living; leading to the "integrated confined animal feeding" facilities. Housing large numbers of animals in areas or buildings smaller than the traditional "hog pen" or cow pasture, increases the public's concern for odor production, groundwater and surface water quality. As South Carolina's urban areas grow into traditional agricultural areas, bringing with it large populations of "non-agricultural" people, public concerns related to agricultural facilities also grow.

Soil, Water, and Air Quality Concerns

While South Carolina has been regulating agricultural facilities since the early 1970's, many states in the United States have not had any regulatory or oversight program for these facilities until recent years. Unlike South Carolina, this has led to uncontrolled growth in our neighboring states. North Carolina's annual swine production is approximately 10 million swine, which ranks it 2nd in the nation behind Iowa. South Carolina's annual swine production is approximately 300,000 swine, which ranks it 24th in the nation. This unrestrained growth in the swine industry, which traditionally uses lagoon/spray field technology for manure treatment, has lead to increased soil, water, and air quality concerns for these facilities. These soil, water, and air quality concerns include:

1. Nutrients and metals (nitrogen, phosphorus, copper, and zinc) release into surface or ground water,

2. Pathogenic bacteria in manure,

3. Air emissions (ammonia nitrogen, greenhouse gases, dust, and odor).

If a facility's manure management plan is not sited, designed, or managed properly, these concerns can easily become reality. There is a national and a global emphasis being placed on the development of **"Alternative Treatment Methods for Animal (Swine) Manure."**

Possible Components of Alternative Treatment Methods

All farms are different: soil type, quantity of land, location, topography, distance to waters-of-the-state, distance to the watertable, management capabilities, available time, available capital, and operator commitment to treatment system. No one treatment system may be the appropriate choice for all farms. Care should be taken when evaluating the effectiveness of a treatment system. A system that appears to be the most environmentally-friendly, may be the result of good management and not the result of a complex manure treatment system. Most researchers believe the optimum system for any given farm will be a combination of several technologies. Some of the possible components of an alternative treatment method are listed below:

1. Dietary Manipulations,
2. Storage Tanks,
3. Underfloor Ventilation,
4. Windbreak Walls Around Ponds and Exhaust Fans,
5. Washing Walls/Wet Scrubbers in Houses and on Exhaust Fans,
6. Bio-filters/Biomass Filters on Exhaust Fans and in Treatment Ponds,
7. Anaerobic Digestion,
8. Aerobic Digestion,
9. Bio-covers for Storage and Treatment Structures,
10. Solid Separation,
11. Composting of Separated Solids,
12. Aerobic Up-flow Bio-filter/Activated Sludge with Extended Aeration,
13. Sequencing Batch Reactors (SBR),
14. Ozonation of Effluent Streams,
15. Chemical Additives to Reduce Odor.

Part II -

Alternative Swine Manure

Treatment Methods

Research and Development Projects

Alternative Swine Manure Treatment Methods Research and Development Projects

This section provides a brief overview of the animal manure treatment research projects which are currently underway at different land grant universities and other agriculture research organizations across the United States. Due to the complex performance standards used to evaluate these alternative technologies, this section will not attempt to provide an evaluation of the different technologies. The information offered in this section should not be considered to be the extent of all research being performed. It is merely a sampling of what is taking place across the United States as well as around the world.

North Carolina State University Research

The recent increase in pork production in the eastern portion of North Carolina has led to concerns regarding the protection of the environment and the need for additional research into alternatives to the "traditional lagoon/spray field technology." Many researchers are quick to point out that when properly sited, designed, constructed, and managed, "traditional lagoon/spray field technology" can provide effective, reliable treatment of animal manure. These same researchers also point out that environmental concerns cannot be overlooked and must be examined closely (North Carolina State University College of Agriculture and Life Sciences, 2000).

One of the foremost areas in the United States for research in the area of animal and poultry manure treatment is North Carolina State University (NCSU). North Carolina State University (NCSU) has developed an Animal and Poultry Waste Management Center located in Raleigh for the purpose of researching alternative methods for the handling and treatment of animal and poultry manure. The recent attention that has been directed at the pork industry in eastern North Carolina has placed the Animal and Poultry Waste Management Center at NCSU in an ideal position to provide the much needed research facilities.

In July of 2000, an Agreement was made between the Attorney General of North Carolina and Smithfield Foods, Inc., and its subsidiaries. This Agreement was, in part, to provide $15 million along with other resources to NCSU for the development of "Environmentally Superior Technologies" that may serve as alternatives to "traditional lagoon/spray field technology." "Environmentally Superior Technologies" is defined according to the Agreement as "any technology, or combination of technologies that (1) is permittable by the appropriate governmental authority; (2) is determined to be technically, operationally, and economically feasible for an identified category or categories of farms and (3) meets the following performance standards:

1. Eliminate the discharge of animal waste to surface waters and groundwater through direct discharge, seepage, or runoff;

2. Substantially eliminate atmospheric emissions of ammonia;

3. Substantially eliminate the emission of odor that is detectable beyond the boundaries of the parcel or tract of land on which the swine farm is located;

4. Substantially eliminate the release of disease-transmitting vectors and airborne pathogens; and

5. Substantially eliminate nutrient and heavy metal contamination of soil and groundwater." (North Carolina State University College of Agriculture and Life Sciences, 2001).

The NCSU swine manure treatment research project consist of several different manure treatment processes. The systems are described as ranging "from simple to operationally complex." Many of the processes use the "traditional lagoon/spray field" infrastructure while others require significant changes to this infrastructure. The sixteen (16) technology categories which are being evaluated are briefly outlined below:

1. In-ground ambient temperature anaerobic digester / energy recovery / greenhouse vegetable production system,

2. High temperature thermophilic anaerobic digester (TAnD) energy recovery system,

3. Solids separation / constructed wetlands system,

4. Sequencing batch reactor (SBR) system,

5. Upflow biofiltration system,

6. Solids separation / nitrification-denitrification / soluble phosphorus removal /solids processing system,

7. Belt manure removal and gasification system to thermally convert dry manure to a combustible gas stream for liquid fuel recovery,

8. Ultrasonic plasma resonator system,

9. Manure solids conversion to insect biomass (black soldier fly larvae) for value-added processing into animal feed protein meal and oil system,

10. Solids separation / reciprocating water technology system,

11. Micro-turbine co-generation system for energy recovery,

12. Belt system for manure removal,

13. High-rate second generation totally enclosed Bion system for manure slurry treatment and biosolids recovery,

14. Combined in-ground ambient digester with permeable cover / aerobic blanket - BioKinetic aeration process for nitrification-denitrification / in-ground mesophilic anaerobic digester system,

15. Dewatering / drying / desalinization system, and

16. Solids separation / gasification for energy and ash recovery centralized system (Williams, C.M. 2001).

The research on these alternative treatment processes is currently underway. Much of the research has not been completed to the point that useful data has been obtained. Researchers continue to have concerns regarding whether many of the individual systems can meet all the required performance standards. It is believed a "combination of technologies" will ultimately provide the best overall performance (Williams, C.M. 2001).

United States Department of Agriculture – Agricultural Research Service (USDA-ARS) Florence, SC

Under the direction of Dr. Patrick Hunt, the USDA-ARS in Florence is evaluating and designing alternative animal manure treatment processes which are described to be "passive, low, and high technological methods." The passive approach involves the use constructed wetlands to capture and transform the nutrients found in animal manure (Hunt, Patrick 2000). Wetlands have long been viewed as Nature's own treatment process for many naturally occurring environmental pollutants.

The USDA-ARS in Florence low technology approach involves developing more efficient methods of solid separation. Solid separation can reduce odor from lagoons by reducing the organic load being treated by the lagoon. However, the odor from the separated solids must also be considered (North Carolina State University College of Agriculture and Life Sciences, 1998). Solid separation can allow the treatment methods to be custom designed for both the liquid and solid waste streams.

The high technology approach involves treatment processes that include nitrification/denitrification reaction units as well as phosphorus removal units. The research will also involve evaluating the effect of manure land application on soil phosphorus and element accumulation in the soil (Hunt, Patrick 2000).

United States Department of Agriculture – Agricultural Research Service (USDA-ARS) Ames, Iowa

Brian Kerr is organizing a research project at the USDA-ARS in Ames, Iowa to evaluate the effect of swine diet manipulation on the production of odor from swine manure. The project is also evaluating microbe populations in the swine digestive system in hopes of being able to alter this population to reduce odor and improve nutrient utilization (Kerr, Brian 2000).

Research has shown that by altering the microbial population in an animal's digestive system and/or adding odor-reducing material to the diet, odor production and nutrient concentration in freshly excreted manure can be reduced. This dietary and microbial manipulation can be done without the risk of decrease in growth performance or animal health (North Carolina State University College of Agriculture and Life Sciences, 1998).

United States Department of Agriculture – Agricultural Research Service (USDA-ARS) Clay Center, Nebraska

Transmission of pathogenic microbes, such as Salmonella and Campylobacter, from animal manure to meat and/or meat products is a significant concern to swine producers and consumers because of potential health risks. The U.S. Meat Animal Research Center in Clay Center, Nebraska is conducting a research project to reduce the nutrients and pathogens in swine manure. This reduction in nutrients and pathogens could reduce the adverse environmental effects of high nutrients loads in soils and prevent the potential transmission of pathogens to the meat supply. (Ferrell, Calvin. 2000).

The U.S. Meat Animal Research Center in Clay Center, Nebraska is also evaluating the conservation of manure nutrients and odor reduction in swine confinement facilities. This reduction in nutrient loss and odor production will be accomplished by use of microbial enriched biofilters and biocovers to change offensive odor to non-odorous compounds. The research project is also focusing on the development of methods to eliminate or , at a minimum, reduce the microbial activities, which produce offensive volatile organic compounds (Varel, Vincent. 2001).

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Alternative Swine Manure Treatment Research and Development Projects

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Part III -

Alternative Swine Manure

Treatment Methods

Available From

The Private Sector

Alternative Swine Manure Treatment Methods Available From The Private Sector

This section provides a brief description of the animal manure treatment processes that are currently available through private companies. The contact information for each company is also provided. All of the processes provide some form of odor reduction, pathogen reduction, and/or nutrient stabilization. Obviously, some processes provide greater benefits in one area and, possibly, less in another. Due to the complex performance standards used to evaluate these alternative technologies, this section will not attempt to provide an evaluation of the different technologies. Some of the treatment processes have been evaluated by an independent research group, while others have not. The information included in this section should be considered for information only. Further investigation should be performed before any of these technologies are committed to being used on any facility. Product information has been submitted to the Department on each of these alternative treatment options. This information is available for review upon request. Inclusion in this section should not be viewed as an endorsement by the South Carolina Department of Health and Environmental Control. The treatment systems and companies included in this section should not be considered the extent of all alternative treatment systems and companies. Many other companies and treatment systems exist in the United States as well as other countries.

ERAC-USA

John Candler of Oklahoma developed the swine manure treatment process offered by ERAC-USA. The process is referred to as a "closed circuit wastewater purification system." The system uses ozone to treat the swine manure.

The open lagoon or storage pond is eliminated. According to the product information the liquids are recycled back into the houses similar to the traditional lagoon operation but the odors have been greatly reduced if not eliminated. The solids are efficiently and effectively separated and can be land applied with minimal odor production. By the treating the wastewater with ozone, pathogens have been removed from the solids and liquids, odors are dramatically reduced, and air quality in the houses has improved to the point animal health has increased resulting in better feeding conversion. Better feed conversion results in increased profits for the farmer. With further development, it is believed the system can treat the liquids to the point they can be recycled back into the houses as drinking water for the animals.

Contact Information:
John Candler
ERAC-USA
3908 E. 26th Street
Tulsa, OK 74114-4712
Voice: 918-712-0500
Fax: 918-712-0501
Email: jccan1@earthlink.net
Website: http//www.nopollute.com

EcoRenew- The NoLagoon System

The EcoRenew system uses a highly efficient solids separator to separate the solids and liquids into two streams. The liquid portion is recycled back to the houses as flush water or further evaporated using a solar powered "smart" evaporator. The remaining products from the evaporated liquids are salts to be used a fertilizer. The solid portion is burned in a dryer/combustor and the remaining product is ash which is also used as fertilizer.

The benefits of the system are reduced odors and harmful gas emissions for the confinement houses, elimination of the need for a lagoon or storage pond, and pathogen reduction.

Contact Information:
Steven Kobler, President
EcoRenew, Inc.
313C Glen Echo Lane
Cary, NC 27511
Phone: 919-852-0800
Fax: 919-852-0600
Email: skolber@bellsouth.net

S.S.S. USA (Super Soil Systems USA, Inc.)

This system includes solids separation at 97% efficiency, nitrogen removal using nitrification/denitrification technology, and soluble phosphorus removal. The solids are composted and used as organic fertilizer. The liquid is treated to reduce pathogens, nitrogen, and phosphorus. This liquid is then recycled back to the houses as flush water. By reducing the pathogens, nitrogen, and phosphorus in the recycled water, it provides enhanced animal health and reduced threat to the environment. The excess water from the liquid treatment can be stored in an above ground tank or existing lagoon and utilized for irrigation purposes. Excess water has been treated to ammonia and phosphorus concentrations of less than 10 mg/L and BOD at less than 30.

The benefits of the system are elimination of odors; pathogen reduction in flush water, excess water, and solids; healthier animals; and solids that can be marketed as organic fertilizer.

Contact Information:
Lewis M. Fetterman, Chairman & CEO
S.S.S. USA
Super Soil Systems
P.O. Box 306
Hickory Grove Road
Clinton, NC 28328
Phone: 910-592-3735
Fax: 910-590-0040

Bion Environmental Technologies, Inc.

The treatment process offered by Bion Environmental Technologies, Inc. uses a combination of earthen or synthetically lined basins along with enhanced natural microbial processes to treat both the liquid and solids portion of the waste stream.

The system begins by the total waste stream emptying into an initial basin. This basin is aerated to stimulate the natural microbial growth. These microbes begin to reduce the odorous compounds present in the manure. The effluent then flows from the initial basin into one of two "Solids Ecoreactor" cells. The cells are designed to de-water the solids, essentially, separating the solids from the liquid portion. The two cells work in parallel. While one cell is drying and curing, the other is filling. The solids captured in the "Solids Ecoreactor" cells are organic material, which can be further processed off site into organic fertilizer. The liquid from the solids cells flow into a second aerated basin where additional microbial growth is stimulated. The retention time is longer in the second aerated basin than the initial basin; therefore, odors, nutrients, and pathogens in the waste stream are further reduced. The liquid from this basin is recycled back to the houses as flush water or can be diverted to a third basin if additional treatment is desired. A "Polishing Ecoreactor" can be added to the end of the cycle to optimize the treatment. This reactor is similar to a constructed wetlands.

Contact Information:

Bion Technologies, Inc.
138 Uzzle Industrial Drive
Clayton, NC 27520
Phone: 919-934-3066
Fax: 919-934-5218

IESS (International Ecological Systems & Services)

International Ecological Systems & Services has to offer two alternative treatment processes for swine manure. Both of these systems provide for a reduction in odor and other gaseous emissions, nutrient reduction, and reduced pathogen concentrations.

The first system is referred to as a "Bio-Kinetic Aeration System." The system consists of a covered traditional anaerobic lagoon to initiate the treatment process. From the covered anaerobic lagoon, the effluent flows into a secondary aeration basin. The basin is aerated by perforated aeration tubes lain on the bottom of the basin which speeds the growth of beneficial microbes. The basin is also divided into three cells. The third cell contains a biofilter curtain with imbedded cultured bacteria. The biofilter provides the final polishing of the liquid before it is transferred back to the houses as flush water or stored for land application as irrigation water.

The second system is referred to as a "Bio-Kinetic Aeration System with Solids Removal." This system is similar to the first except the covered traditional anaerobic lagoon has been replaced by a primary aeration cell, which is aerated by the use of bottom-lain perforated aeration tubing.

The effluent flows from this primary aeration cell to a centrifuge where the solids are separated from the liquid portion. The solids can be land applied and/or composted into organic fertilizer. The liquid portion flows from the centrifuge into the secondary aeration basin similar to the first treatment system. From this point, the process is identical to the first system.

Contact Information:

Gordon F. (Bucky) Pearson, Jr.
IESS (International Ecological Systems & Services)
PO Box 21240
B1 Oak Park Plaza
Hilton Head Island, SC 29925
Phone: 843-681-8292
Fax: 843-681-4286

Part IV -

Cost of Traditional and Selected Alternative Manure Treatment and Storage Systems for Swine Finishing Farms: Summary of Results

Cost of Traditional and Selected Alternative Manure Treatment and Storage Systems for Swine Finishing Farms: Summary of Results

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July 21, 2001

The actual cost of a particular manure treatment and storage system can vary greatly from farm-to-farm. Some of the variables that can effect the cost include: farm size, type of structures used to provide the containment needed for a given system, the depth to the seasonally high water table, the cost of the liner needed for earthen basins, the topography of the site, and the proximity to surface water. In order to make a fair comparison between systems it is imperative that all of the siting limitations and financial assumptions be held constant.

A great deal of time and effort was invested in developing cost functions for earthen basins constructed with various lining materials (compacted clay, synthetic, and geo-clay), lined steel tanks, concrete settling basins, and trickling filters. The cost data needed to develop these functions was obtained from the NRCS (Atkins and Henry, 2001), and manufactures. The details of the cost functions used are not presented here, but will be included in a more detailed report that will be completed over the next few months. In addition, some systems that were identified as potential alternatives (such as treatment with ozone and low-power aeration with bioaugmentation) have not been included since neither performance data, design standards, or a complete capital requirement for all components are unavailable at this time. Some consulting firms and other interested partied are working to provide the needed information so that these systems can be included in the future.

The purpose of this report is to provide a summary of the results that we have been able to obtain to date.

The financial assumptions used in these analyses were taken from detailed information provided by Farm Credit (Shuler, 2001). The analysis used for the manure treatment and storage systems was a cash-based partial budget. A partial budget allows one to study the cost of a particular portion of the total capital investment for a given enterprise assuming all other variables are held constant. The simplicity of this approach allows a large group of alternatives to be compared quickly. However, it should be noted that the partial budget results are most useful in ***excluding*** alternatives that do not meet a particular financial criterion. That is, it can be used to narrow the field of alternatives that appear to hold promise. It is too simple of an approach to decide which alternative is most cost-effective in a particular situation. A more detailed performance and financial analysis is required for the final decision.

The assumptions used in the partial budget analysis were as stated below.

1. The total investment per hog space for animal housing and support facilities (not manure system) is $94.36/hog space.
2. The allowable budget for manure treatment and storage ranges from $17.68/hog space to $19.86/hog space.
3. The annual fixed costs for facilities and manure system are calculated based on an interest rate of 10.50% for 10 years with no down payment.
4. The number of hogs sold per year is calculated based on a 2.2% mortality rate and 2.6 pigs placed per year per hog space (2.6 turns per year).
5. Operating expenses (utilities, taxes, insurance, maintenance) were set at $4.55/hog space.
6. The costs for land application, fuel and other operating expenses not included in the loan amount is $0.22/hog sold.

The annual fixed costs (assuming 10.5% interest and a loan period of 10 years) was calculated as:

$$FC = 0.1663 \times CC\ , \tag{1}$$

where:

CC = the capital cost, and
FC = the annual fixed costs (principle and interest).

The fixed cost per hog sold can be calculated from the following formula (assuming 2.2% mortality and 2.6 turns per year):

$$FCHS = FC \div (NHS \times 2.54), \tag{2}$$

where:

FC = the annual fixed costs from equation 1,
NHS = number of hog spaces on the farm,
FCHS = fixed cost per hog sold.

Based on the assumptions as defined by equations 1 and 2, and confidential information provided by the lender it was determined that:

- The fixed cost for facilities is $6.18 per hog sold.
- The fixed cost for manure treatment and storage can vary from $1.16 to $1.30 per hog sold.
- The operating expenses for the hog farm are $2.01 per hog sold.
- The family living per hog sold ranges from $2.11 to $2.25 per hog sold depending on manure storage and treatment cost.

The relationship between family income and manure treatment and system cost is shown in Figure 1. These results indicate that family income goes to zero when the manure system cost reaches $3.40 per hog sold. The normal cost range for manure systems in the range of $1.16 to $1.30 per hog sold provides a family income of $2,100 to $2,250 per 1,000 hogs sold (Number of hogs sold = *NHS x 2.54*). Therefore, the family living for a swine farm with:

- 3,200 head of finishing swine will range from $17,069 to $18,288 per year,
- 6,400 head of finishing swine will range from $34,138 to $36,576 per year,
- 8,000 head of finishing swine will range from $42,672 to $45,720 per year, and
- 10,000 head of finishing swine will range from $53,340 to $57,150 per year.

These results indicate that 6400 to 8000 head of finishing swine are required to provide enough income to support a family depending on the number of dependents. Anything less than 6000 head is a part-time enterprise.

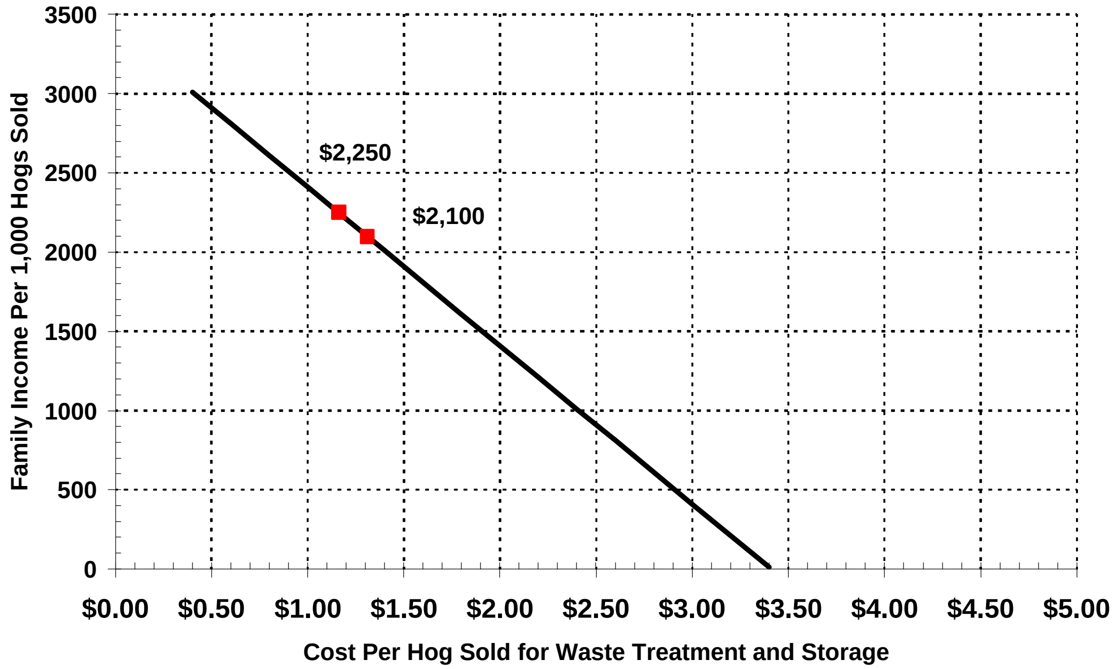

Figure 1. Effect of manure treatment and storage system cost on family income based on the defined assumptions.

The fixed costs were computed for several manure system alternatives. The criterion used was the fixed cost per hog sold. The maximum acceptable cost was $1.30 per hog sold.

TRADITIONAL LAGOONS

Anaerobic treatment lagoons and storage ponds are the most common type of storage structures used to store swine manure in South Carolina. A treatment lagoon and storage pond may look the same, but they are designed and managed differently.

Anaerobic lagoons used to treat and store animal manure are designed as no-discharge units. That is, the effluent is not discharged to waters of the state. Instead, the treated effluent is used to remove manure from below the slotted floor in a swine facility. Each year, a portion of the surface water is land applied to cropland as fertilizer. The solids, or sludge, level needs to be managed properly and a common recommendation is to agitate and remove 50% of the sludge every 5 years. The sludge/lagoon liquid mixture is rich in organic plant nutrients and is typically also land applied. The components of a traditional animal waste include the following (ASAE EP403.2, 1998):

- anaerobic treatment volume,
- manure and wasted water storage volume,
- sludge storage volume, and
- additional depth for the net rainfall (precipitation - evaporation), the 25-year, 24-hour rainfall event and a freeboard of 1 ft

The lagoon operator must maintain these volumes and depths in order for the lagoon to function properly.

The liquid level of a lagoon must be controlled (by pumping) to maintain the level between the design treatment level and the maximum operating level. The depth for freeboard and the 25-year, 24 hour storm must be maintained at all times.

Treatment Volume and Loading Rate

The treatment volume of a lagoon is determined based on the volatile solids loading rate (pounds of volatile solids per 1,000 cubic feet per day or lb VS/1,000 ft^3-day). The loading rate varies with climate (ASAE EP403.2, 1998). Larger loading rates can be used in warm climates than in cold climates. For example, in the coastal plains of South Carolina, the maximum loading rate that should be used is 5 lb VS/1,000 ft^3-day. However, in Iowa the maximum loading rate is 3.5 lb VS/1,000 ft^3-day. In North Carolina the maximum loading rate is about 4.5 lb VS/1,000 ft^3-day.

Effect of Loading Rate on Odor

The loading rate has a large impact on the amount of odor that is generated from a lagoon (Humenik et al., 1981). Data indicates that at very high loading rates, such as 30 lb VS/1,000 ft^3-day, a significant odor will be produced near a lagoon 80% of the time. If the loading rate is only 1.9 lb VS/1,000 ft^3-day, the odor will be insignificant. These results show that one way to control odor is to use a very small loading rate. However, a lagoon sized based on a loading rate of 1.9 will be very large and expensive to build. The maximum recommended loading rate of 5.0 will have an odor near the lagoon 33% of the time. In South Carolina, the recommended loading rate to minimize odor is 3.8 lb VS/1,000 ft^3-day with an odor frequency of 20%.

The variation in odor frequency with loading rate also indicates why the design treatment volume must be maintained. If solids or sludge are allowed to build up in the lagoon, the treatment volume will be greatly reduced. The decreased treatment capacity has the same effect as an increase in loading rate and will cause an increase in odor frequency.

Effect of Loading Rate on Recycle Water Quality

The final important consideration related to sizing treatment volumes based on loading rates is the quality of recycle water for recharging pits and flushing. The loading rate of a lagoon greatly effects the quality of the water that is recycled through the building to remove manure. The maximum loading rate that should be used if lagoon water is recycled through the building is 5.0 lb VS/1,000 ft^3-day (Barker and Driggers, 1985). Using a lower loading rate, such as 3.8 lb VS/1,000 ft^3-day, will provide recycle water that is relatively low in odor. Inadequately treated lagoon liquid, associated with high loading rates, can increase ammonia levels in the swine buildings and increase odor from the buildings. An old lagoon with excessive amounts of sludge should not be used as a source of recycle water.

Manure and Sludge Volumes

In many cases, lagoons in South Carolina are sized to provide 180 days of storage for manure (includes wasted water), and 10 years of sludge storage. However, the producer and the designer can modify these values on a case-by-case basis. The two major components of sludge are the fixed solids (solids like sand that will never decompose), and volatile solids that require a large amount of time to decompose (more than 5 to 10 years).

Total Lagoon Volume

The total design volumes for swine lagoons are given in Table 1. These volumes are the sum of the treatment volume, 180 days of storage for manure and wasted water, and 10 years of sludge storage.

Table 1. Total lagoon volumes including 180 days of manure and wasted water storage and 10 years of sludge storage. (These values do not include the additional depth required for net rain, the 25-year, 24-hour storm, or required 1 ft free board.)

Farm Type	Average Weight lb/PU[3]	Minimum Size [1] Total Volume ft^3/AU^4	Size to Minimize Odor [2] Total Volume ft^3/AU^4
Farrow-to-Wean	433 lb	2,149	2,433
Nursery	30 lb	3,942	4,479
Farrow-to-Feeder	522 lb	2,433	2,755
Feeder -to- Finish	135 lb	3,942	4,479
Farrow-to-Finish	1,417 lb	3,358	3,813

[1] Loading rate = 5.0 lb VS/1,000 ft^3 -day
[2] Loading rate = 3.8 lb VS/1,000 ft^3- day
[3] PU = production unit. For all farm types with sows the production unit is a sow. For nursery farms a production unit is a pig. For a finishing farm a production unit is a hog.
[4] One animal unit AU = 1,000 pounds of live weight.

Net Rainfall, 25-year, 24-Hour Storm, and Freeboard

Estimates of the additional depth needed to allow for precipitation and freeboard are given in Table 2. These are approximate values, and are intended for general planning purposes. More detailed weather information can be obtained at the local NRCS office for a particular location. In some cases, the required depth will be lower than shown in the table. In the mountains of the Upstate region of South Carolina the values could be larger due to high variations in local rainfall.

Table 2. Approximate depths to add to lagoons or storage structures for net rainfall, rain from a 25-year, 24-hour storm, and freeboard in South Carolina (NRCS field offices can provide more accurate values.)

Region	Net Rainfall Based on Winter Rainfall & Evaporation (inches)	Rainfall From a 25-year, 24-hour Storm (inches)	Total Depth to Add Including 1 ft Freeboard (ft)
Mountains	18	9	3.3
Upstate	13	7.5	2.7
Midlands	8 - 10	6 - 7	2.2 - 2.4
Coastal Plain	6 - 9	6 - 8	2.0 - 2.4

Construction of Lagoons

Most lagoons are constructed as an earthen basin. Earthen basins are earth-walled structures that are partially above or below grade and are designed and constructed to prevent ground water contamination. Common materials used for basin liners are clay-type soils, and plastic synthetic liners (e.g. PVC, HDPE), and geo-clay liners. Geo-clay liners use bentonite between two layers of geotextile to create a liner with low hydraulic conductivity. If the soil near the basin is too porous, clay soil can be obtained from another site. However, the cost of a clay liner may exceed the cost of a synthetic liner if the clay must be transported a large distance (over 5 miles).

Cost of Traditional Lagoons and Assumed Site Restrictions

The cost of a traditional treatment lagoon depends on the type of liner used, the amount of compacted fill required to construct the berms, and the size of the structure. In many areas of the South Carolina coastal plain the depth of a lagoon is limited to 6 ft due to high water tables. The cost of traditional lagoons were estimated for lagoons that have a total depth of 8 ft, and a liquid depth of 6 ft. The entire liquid depth was assumed to be below the natural grade level and the compacted berm provides the additional 2 ft of depth (mainly freeboard, net-rain, and the 25-year, 24-hour storm). ***These same assumptions related to site restrictions were used for all earthen basins included in this study.***

The fixed cost of the lagoons were calculated based on the previously defined assumptions. The results are given in Figure 2 for unlined lagoons (not permitted, shown for comparison only), clay-lined lagoons, synthetic lined lagoons ($0.32/ft^2), and geo-clay lined lagoons ($0.45/ft^2).

On most profitable swine farms the cost for manure treatment and storage ranges from $1.16 to $1.30 per hog sold based on the assumed interest rate, loan period, mortality rate, and building turnover rate. The results shown in the figure indicate that current construction costs yield the traditional lagoon a non-viable option regardless of farm size or type of liner used. In fact, few if any traditional lagoons have been built in South Carolina in the last 5 years.

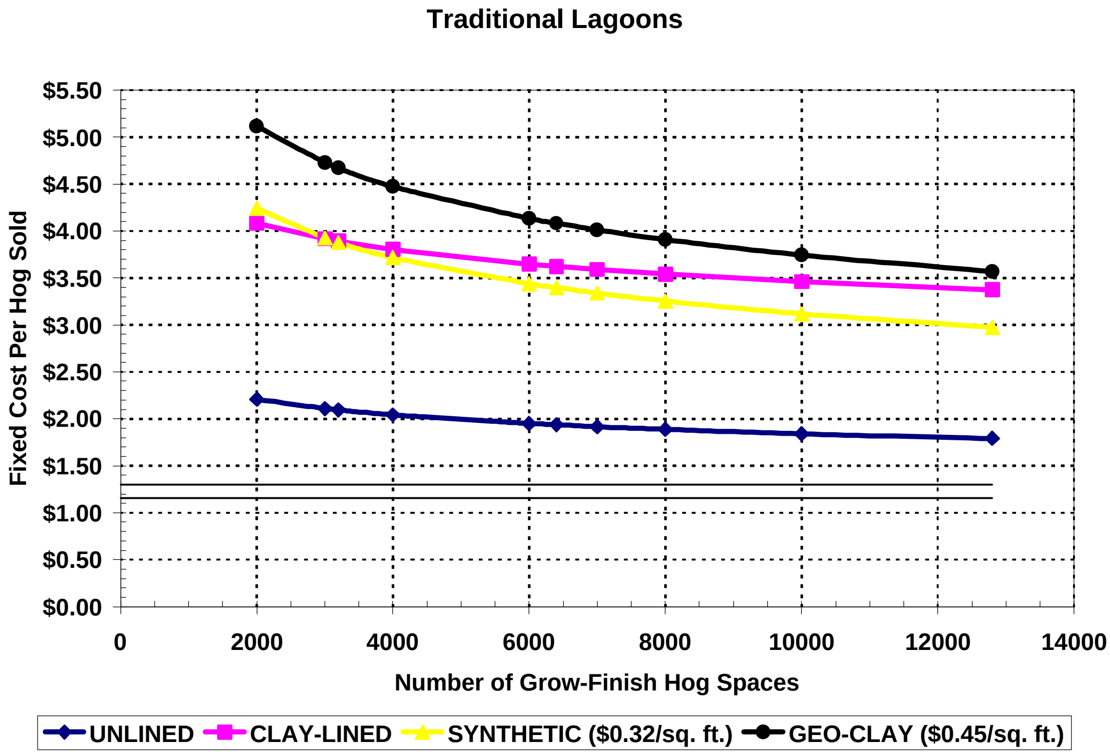

Figure 2. Costs of traditional lagoons based on farm size and type of liner. Typical costs for treatment and storage range from $1.16 to $1.30 per hog sold (shown on graph as horizontal lines).

LAGOONS WITHOUT SLUDGE STORAGE

A treatment lagoon can also be designed without the sludge storage volume to reduce storage and treatment costs. However, most of solids must be agitated, removed, and land applied each year. This hybrid structure provides the treatment volume of a lagoon without the sludge storage volume.

The maximum operating level is the same as for a treatment lagoon. The treatment level is the same as previously described for a lagoon. The liquid level is kept between these two levels except when solids are removed by agitating and pumping.

Recommended design volumes using loading rates of 5.0 and 3.8 lb VS/1,000 ft^3-day are given in Table 3. A lagoon without sludge storage is about half the size of a traditional lagoon.

Table 3. Recommended design volumes for lagoons without sludge storage and swine manure storage structures. (These values do not include the additional depth required for net rain, the 25-year, 24-hour storm, or required 1 ft free board.)

Description	Minimum Volume for 180 days ft^3/AU[1]
Conventional Storage Structures [2]	
Slurry (TS = 5%)	447
Liquid Manure (TS = 1%)	1,224
Lagoon without Sludge Storage	
Loading rate = 5.0 lb VS/1,000 ft^3 - day.	1,992
Loading rate = 3.8 lb VS/1,000 ft^3 - day.	2,529

[1] 1 AU = 1,000 lb live weight

[2] Sized based on manure and wasted water production from finishing swine.

Costs of Lagoons without Sludge Storage

The same liner options and loan assumptions were used to estimate the construction costs of lagoons without sludge storage as were used for a traditional lagoon. The results are given in Figure 3. Only the unlined structures, which are not recommended or permitted in South Carolina, meet the cost criterion for farms with 4000 or more grow-finish swine at any time.

MANURE STORAGE PONDS

A storage pond looks like a lagoon. However, they are not designed based on anaerobic treatment principles. Storage ponds are much smaller, and the potential for strong odor is greater than for a treatment lagoon.

Manure storages are sized to store all of the manure, waterer wastage, and washdown water for a defined storage period. Additional depth is also provided for precipitation and freeboard in the same way as for a lagoon. The entire storage contents are agitated and land applied. In cold climates, 8 to 12 months of storage are required because manure can only be used to fertilize crop or pasture land during the spring and summer. In South Carolina, manure storages are typically sized to contain 180 days (6 months) of manure since grains and forages can be grown much of the year. A land application plan that includes winter and summer crops or forestland can allow the storage period to be reduced. Whatever the case, it is important that the storage structure be sized to provide adequate storage when land application can not occur, and to allow for periods of wet weather. The minimum practical storage period for manure in South Carolina is between 60 and 90 days.

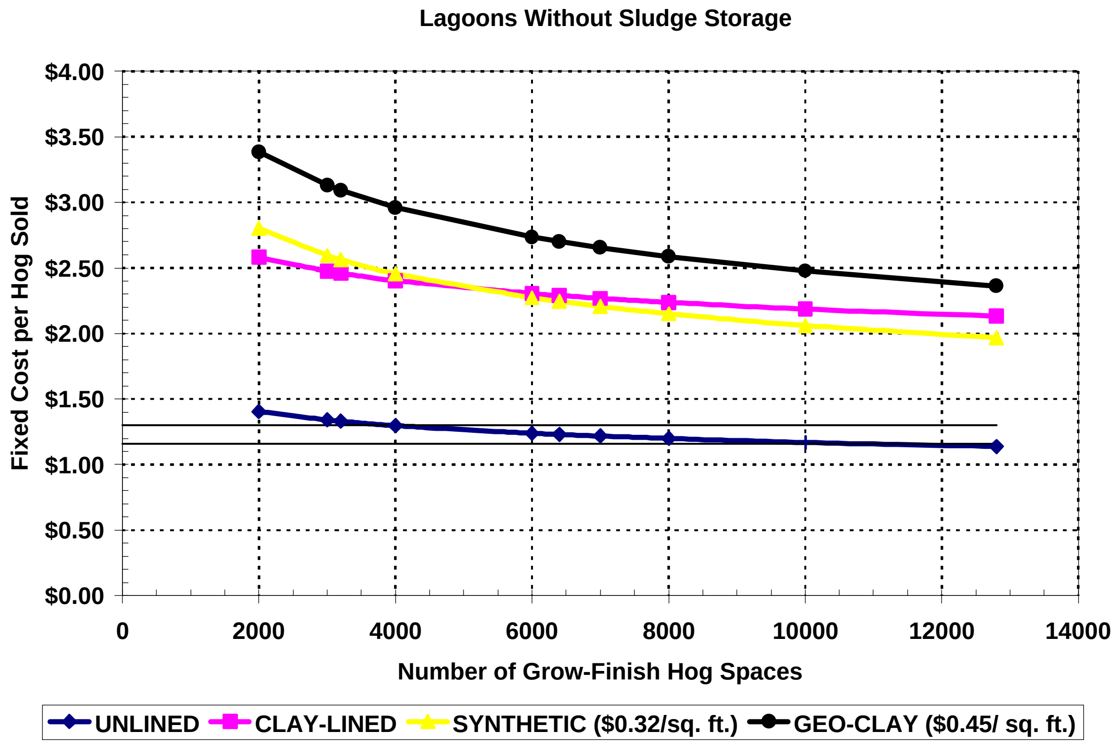

Figure 3. Costs of lagoons without sludge storage based on farm size and type of liner. Typical costs for treatment and storage range from $1.16 to $1.30 per hog sold (shown on graph as horizontal lines).

The contents of a storage pond are agitated so that both solids and liquids are removed during pumping and land application operations. The liquid level must not exceed the maximum operating level.

Design Volumes for Storages

Manure storage structures can be used to store slurry or liquid swine manure. Design volumes for 180 days of storage were given previously in Table 3. Slurry manure storages are typically used in the Midwest and Canada and are included for comparison. Liquid manure storages are used with pit-recharge systems and are about twice as large as a slurry storage. All manure storages are smaller than lagoons and can be less expensive to construct.

A slurry storage (95% moisture or 5% total solids) has very little dilution volume, and the effective loading rate is about 27 lb VS/1,000 ft^3-day. Consequently strong odors are frequent. Liquid manure storage (99% moisture, TS = 1 %) has dilution volume from the water added for manure removal. The loading rate is about 6 lb VS/1,000 ft^3-day. The strength and frequency of odor from a liquid storage is less than for a slurry storage, but the surface water is too strong to be recommended for recycling in both cases.

Cost of Liquid and Slurry Storage Ponds

Liquid and slurry storage ponds can be constructed in the same manner as a lagoon. The main difference is that a much smaller containment structure is required. As a result, the cost of liquid (TS = 1%) and slurry storage ponds (TS = 5%) is much lower as shown in Figures 4 and 5. Liquid storage ponds meet the cost criterion ($1.30/hog sold or lower) for farms with 6,400 grow-finish swine or larger if a clay-lined pond can be used. A synthetic lined pond that cost $0.32/ft^2 is a cost-effective option for 8,000 or more swine. The cost of the geo-clay option exceeds the cost criterion in all cases.

The fixed cost associated with slurry manure storage ponds meet the cost criteria for all types of liners and farm sizes. Therefore, swine manure handling systems that avoid large amounts of water for manure removal are the most cost effective – especially for smaller farms (3,200 to 4,000 head).

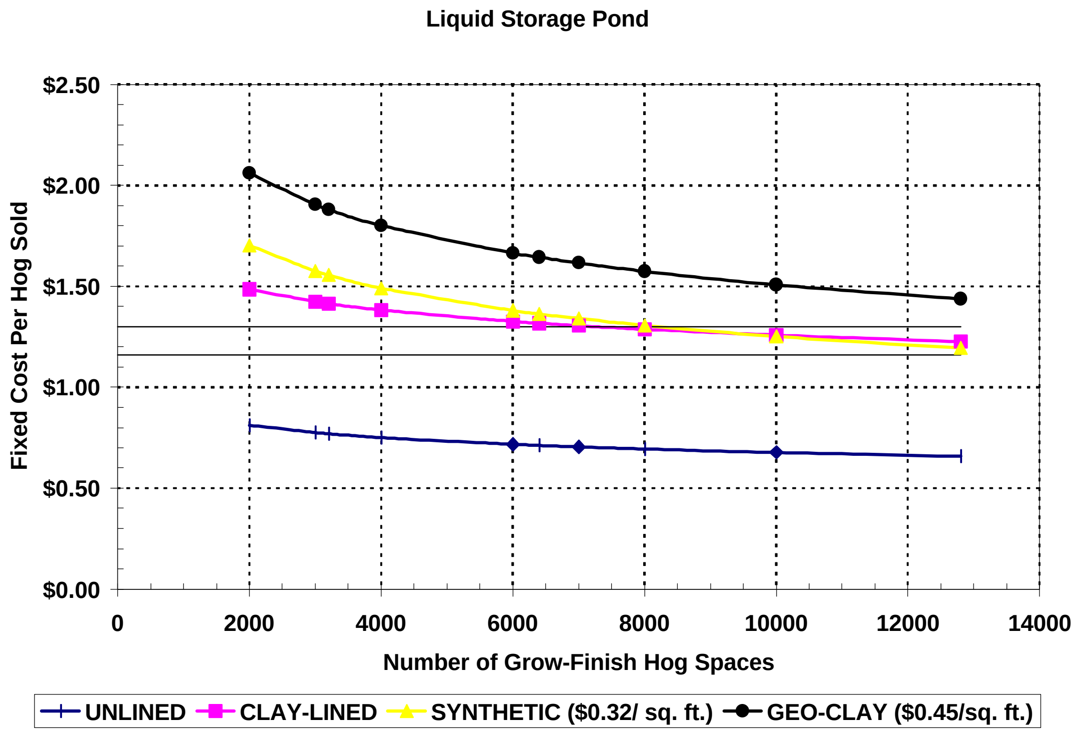

Figure 4. Costs of liquid manure storage ponds (TS = 1%, 180 days of storage) based on farm size and type of liner. Typical costs for treatment and storage range from $1.16 to $1.30 per hog sold (shown on graph as horizontal lines).

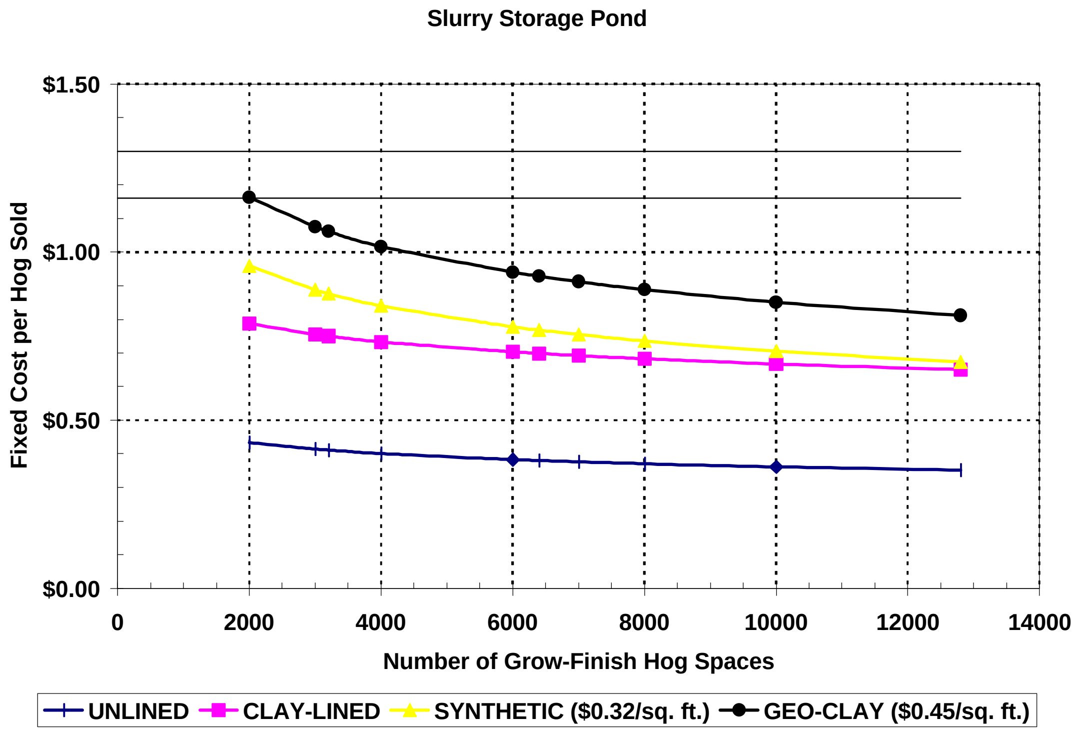

Figure 5. Costs of slurry manure storage ponds (TS = 5%, 180 days of storage) based on farm size and type of liner. Typical costs for treatment and storage range from $1.16 to $1.30 per hog sold (shown on graph as horizontal lines).

SLURRY STORAGE PONDS WITH A GEOTEXTILE COVER

The previous cost results indicated that the least-cost alternative is the slurry storage pond. However, strong odors are common near the structure during agitation and pumping for land application. An effective method of controlling the release of odor from a slurry storage pond is to use a floating cover. Manure is added to the pond below the cover and agitation equipment can be operated below the cover. Research has indicated that covers can greatly reduce odor and ammonia losses from slurry storage ponds.

One of the most practical covers is a geotextile fabric that is made of woven PVC fibers with a UV resistant coating. The cover has a specific gravity that is much less than water (that is, it will float) and has a useful life of 7 to 10 years. A cable system is used to hold the cover in place and to provide enough support to prevent the cover from being drawn into agitation and pumping equipment during land application. The geotextile cover cost was $\$0.11/ft^2$. The costs of a slurry storage pond with a geotextile cover are given in Figure 6.

While the fixed cost per hog sold is 14% greater, on the average, than for an uncovered pond it still provides a cost-effective system for small and large farms. In fact, the fixed cost per hog sold is lower than $1.16/hog sold for all farms with 4,000 hogs or more. If an HDPE liner ($\$0.32/ft^2$) is used the cost of the covered slurry storage can be reduced by about $0.15/hog sold.

The amount of land required to utilize the plant nutrients in slurry will be significantly higher than for a lagoon based on nitrogen. However, ammonium-N losses will be reduced and will result in a higher ratio of plant available-N (PAN) to phosphorous (P_2O_5). Higher PAN/P_2O_5 ratios in manure reduce the extra the amount of nitrogen fertilizer that must be purchased if land application of manure is based on the phosphorous content.

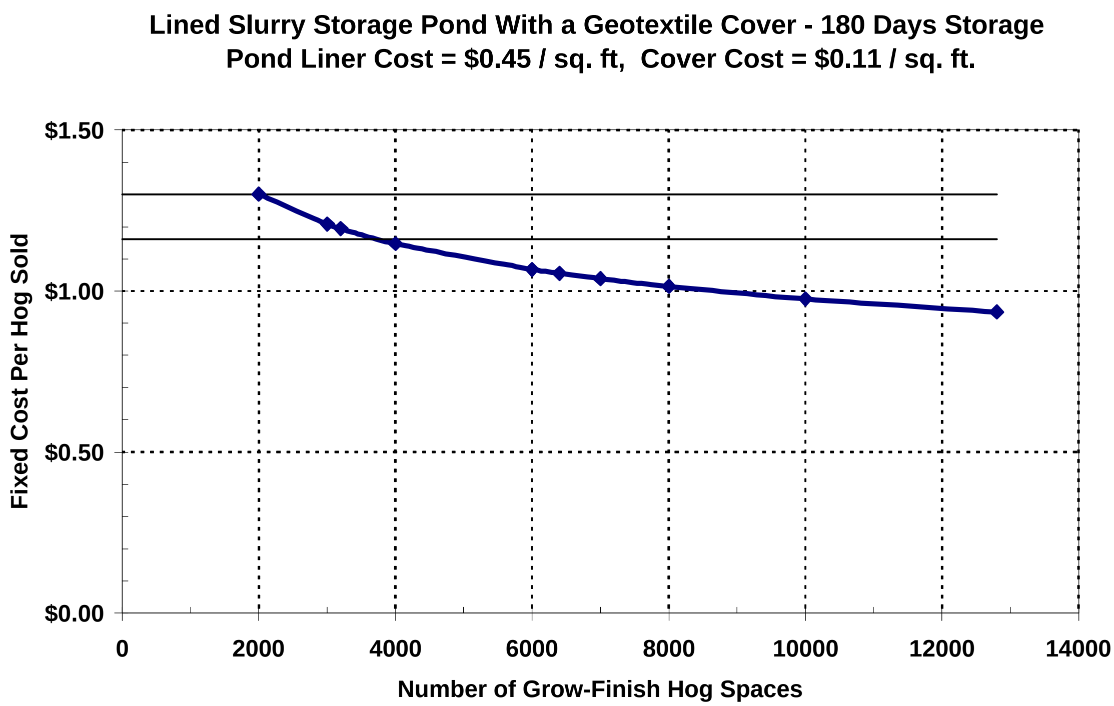

Figure 6. Costs of slurry manure storage ponds covered with a geotextile fabric (TS = 5%, 180 days of storage) based on farm size and type of liner. Typical costs for treatment and storage range from $1.16 to $1.30 per hog sold (shown on graph as horizontal lines).

STORAGE OF SLURRY MANURE IN A DEEP PIT BELOW THE SLOTTED FLOOR

Another manure storage method that is common in the Midwestern US and Canada is the deep pit below the slotted floor. In cold climates, 8 to 12 months of storage in a deep pit is common. Modification of the pit-recharge building that is currently used in South Carolina would involve the addition of 5 feet to the current pit depth of 3 ft. In addition, the floor of the pit would be flat and provision for manure removal would be required along with ventilation modifications. An 8 ft deep pit would provide 180 to 200 days of storage and would add $0.84/hog sold to the cost of the building. Therefore, this type of system would save $0.32/ hog sold for treatment and storage cost. The other advantage is that all rainwater would be excluded from the manure. Management practices to reduce odor from the pit (such as specially designed ventilation systems) and hazardous gas conditions during pit emptying must be addressed. However, this type of system has been used successfully for over 20 years in other parts of the U.S. and Canada.

ABOVE GROUND STORAGE TANKS

Very few swine farms in South Carolina use above ground lined steel tanks to store manure. Storage tanks can be used to store slurry or liquid manure. Liquid manure from a tank is typically not used as a source of flush or pit-recharge water unless a treatment process is used following the storage tank. Additional tank depth must be provided to contain the net rainfall, the 25-year, 24-hour storm, and to provide the needed freeboard.

Above ground tanks are typically only considered in areas where high water tables or karst geology prohibit the use of below grade storage structures due to high cost. The costs of lined steel above ground tanks as a function of storage period and farm size are given in Figure 7. Tanks are only an option for 60 days or less of containment and on large swine farms (12,000 head and up). The extreme economy of scale associated with using above ground tanks is related to the ratio of wall cost to bottom cost. Larger tanks provide more storage volume per square foot of wall and as a result have a lower cost per unit storage volume.

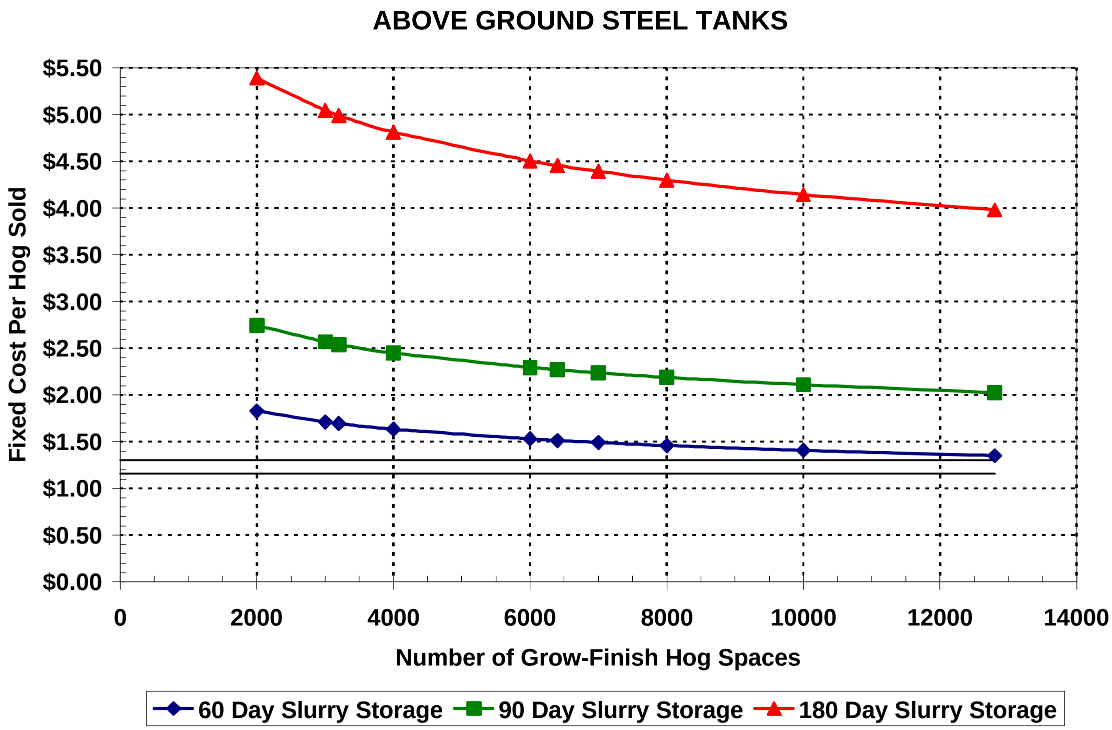

Figure 7. Costs of lined steel above ground tanks for slurry manure storage (TS = 5%) based on farm size and storage period. Typical costs for treatment and storage range from $1.16 to $1.30 per hog sold (shown on graph as horizontal lines).

PSYCHROPHILIC ANAEROBIC DIGESTER FOLLOWED BY A SYNTHETIC LINED POLISHING POND

Research was begun on low-temperature mesophilic (86 °F) and psychrophilic (60 to 77 °F) anaerobic digestion in the late 1970's and early 1980's (e.g. Humenik and Overcash, 1976; Pos et al., 1985; Safley and Westerman, 1990). The goal of much of the research on low-temperature anaerobic digestion was to gather data in order to develop a less complicated on-farm digester that would be less costly to construct and maintain. The types of digesters that were studied ranged from an intermittently mixed digester operated at temperatures of 68 to 77 ° F to anaerobic lagoons (45 to 85 °F) fitted with a cover to collect biogas (Pos et al., 1985; Humenik and Overcash, 1976; Safley and Westerman, 1990; Wimberly, 1994; Saele, 1998). A model of the operating characteristics of a psychrophilic anaerobic digester was developed by Chastain and Linvill (1999) and a recent review of anaerobic digestion is provided by Chastain et al., (1999).

The loading rate for a psychrophilic anaerobic digester used to treat swine manure ranges from 10 to 25 lb VS/1000 ft^3-day. Use of a higher loading rate, such as 25 lb VS/1000 ft^3-day requires sludge removal every 8 to 12 months but results in a significantly lower cost treatment structure.

The main goal of applying anaerobic digestion on a swine finishing farm is to treat liquid manure to provide an effluent that can be recycled for manure removal and to control odor production. Methane will be produced, however the cost of using the gas to generate electricity is too great at this time. Instead, the biogas is simply flared off. In the future it may be cost effective to add a fuel cell or a micro-gas turbine to provide electrical energy for the farm. For the present analysis, the anaerobic digester is viewed as a treatment method and not a source of energy.

A synthetic lined polishing pond (sized based on a loading rate of 5 lb VS/1,000 ft^3-day) is used to store and provide additional treatment of the effluent prior to recycle. Pumping onto a small spray field based on the plant nutrient content will control the liquid level of the polishing pond.

The fixed costs of using a single psychrophilic anaerobic digester, with a loading rate of 25 lb VS/1,000 ft^3-day, followed by a polishing pond are given in Figure 8. Two cover options are given for the digester. One option uses a gas collection system that covers 80% of the liquid area and collects the majority (80 to 90%) of the biogas and achieves a high level of odor control. The other cover option covers the entire digester in such a way that all rainwater is excluded from the digester. All of the biogas is collected.

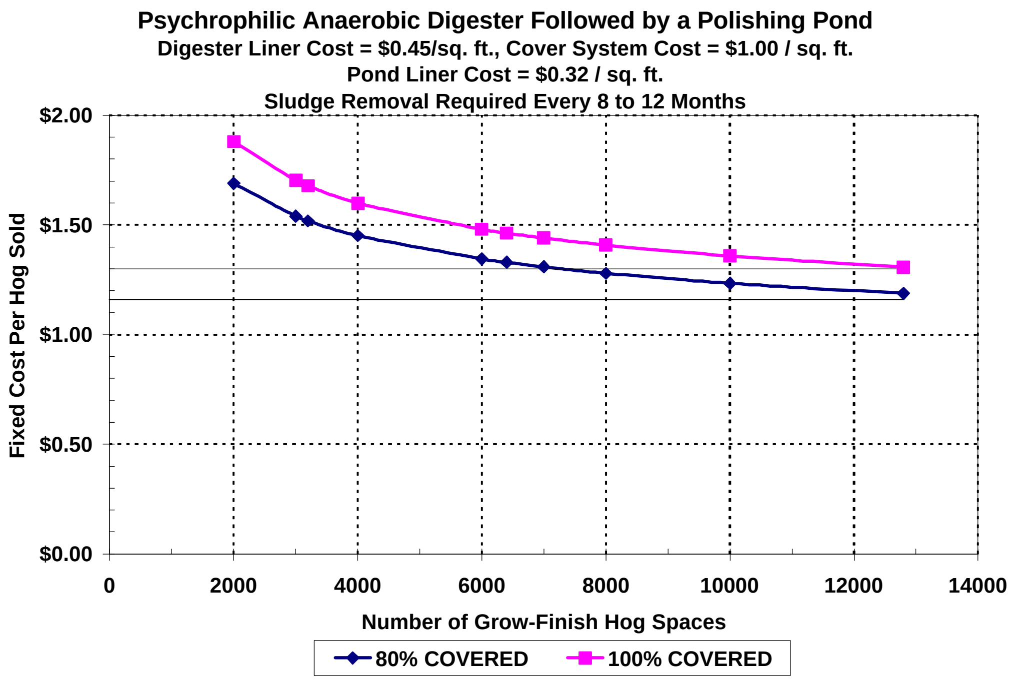

Figure 8. Costs of psychrophilic anaerobic digesters (Loading Rate = 25 lb VS/1,000 ft^3-day) and polishing ponds based on farm size and fraction of digester liquid surface covered. Typical costs for treatment and storage range from $1.16 to $1.30 per hog sold (shown on graph as horizontal lines).

The results given in the figure indicate that the 80% covered system is cost-effective for swine finishing farms with 7,000 head or more. It is expected that a reduction in liner or cover cost would allow this technology to be cost effective for 6,400 head also. For example, using a liner that cost $0.32/ft2 for the digester instead of the geo-clay liner ($0.45/$ft^2$) can reduce the system cost by $0.10 to $0.15/hog sold. The additional cover material required to exclude rainwater from the digester adds a significant cost. Therefore, the 100% covered system is only cost effective for farms that house 12,800 or more finishing swine if the digester liner cost is $0.45/$ft^2$. However, reducing the liner cost to $0.32/$ft^2$ would make the 100% covered system cost effective for 8,000 head or more of finishing swine.

MECHANICAL SEPARATOR FOLLOWED BY A PSYCHROPHILIC ANAEROBIC DIGESTER AND A SYNTHETIC LINED POLISHING POND

One way to reduce the size of an anaerobic digester is to remove a fraction of the volatile solids (VS) using liquid-solid separation. A mechanical separator can be implemented in such a way that 20% of the volatile solids can be removed from liquid swine manure (Chastain et al., 1998). The effluent from the mechanical separator would be treated using a psychrophilic anaerobic digester followed by a polishing pond. The separated solids can be land applied directly or be incorporated into a composting process. The costs for this system are given in Figure 9.

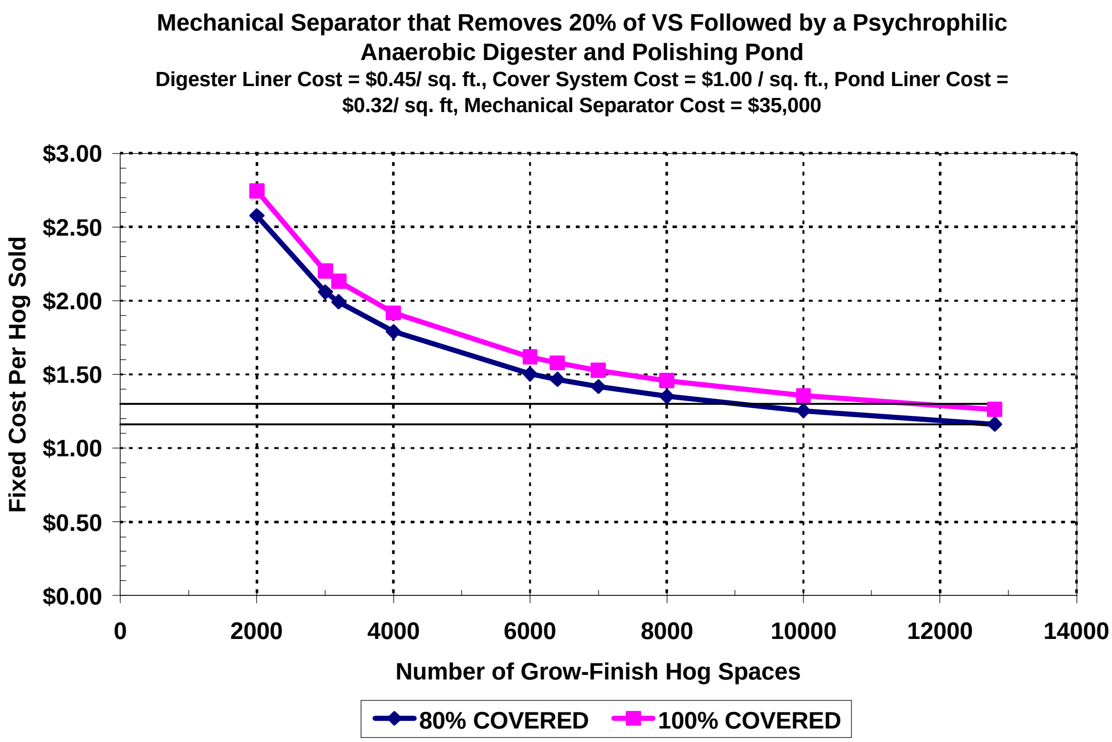

Figure 9. Costs of primary treatment using a mechanical separator followed by a psychrophilic anaerobic digester (Loading Rate = 25 lb VS/1,000 ft^3-day) and polishing pond. Typical costs for treatment and storage range from $1.16 to $1.30 per hog sold (shown on graph as horizontal lines).

The results shown in Figure 9 indicate that the combination of mechanical separation and anaerobic digestion meets the cost criterion for farm sizes of 9,000 head or more if 80% of the digester is covered. If a cover that excludes rainwater is used (100%) the farm size needs to be 12,000 head or more. Again, reduction of the digester liner cost from $0.45/$ft^2$ to $0.32/$ft^2$ reduces the cost by 10 to 15 cents per hog sold and could make this option a viable alternative for farms with 7,000 head or more for the 80% covered system and 9,000 head or more for the 100% covered system.

The additional fixed cost associated with the mechanical separator almost balances with the reduction in digester and polishing pond. For example, at a farm size of 9,000 head the mechanical separator adds 4 cents to the fixed cost per hog sold as compared to the system that uses the psychrophilic anaerobic digester (80% covered) and polishing pond alone ($1.30/hog sold versus $1.26/hog sold).

SETTLING TANK THAT SPLITS THE WASTE STREAM INTO A SOLIDS FRACTION AND A LIQUID FRACTION. SOLIDS TREATED AND STORED IN A PSYCHROPHILIC ANAEROBIC DIGESTER. LIQUIDS TREATED IN A SEPARATE PSYCHROPHILIC ANAEROBIC DIGESTER AND A SYNTHETIC LINED POLISHING POND

A common practice at municipal waste treatment plants is to use gravity settling as primary treatment for the waste stream. In effect, this splits the waste stream into a solids and liquid fraction. The solids are often treated using an anaerobic digester. The liquid fraction is treated using either anaerobic or aerobic processes. The main difference between the municipal system and the swine system is that the municipal system eventually discharges the liquid fraction into waters of the state whereas the goal on the swine farm is to provide an effluent that is clean enough to recycle through the barns for manure removal. Excess water (rain, etc) is land applied as needed.

A simplified version of this basic treatment system can be designed for a swine farm using the following components: (1) a settling tank to serve as a simple primary clarifyer, (2) a psychrophilic anaerobic digester for treatment and storage of solids, (3) a separate psychrophilic anaerobic digester for treatment of the liquid fraction, and (4) a polishing pond to provide additional treatment and storage prior to recycle or land application.

The costs of the defined system are given in Figure 10. The 80% covered system is cost effective for 5,700 or more finishing swine. The 100% covered system meets the cost criterion at 8,000 or more finishing swine. However, reduction of the liner cost for the solids digester can reduce the cost enough (10 cents per hog sold) to meet the cost criterion for the 80% covered system at 4,000 head and the 100% covered system at 6,400 head.

SETTLING TANK THAT SPLITS THE WASTE STREAM INTO A SOLIDS FRACTION AND A LIQUID FRACTION. SOLIDS TREATED AND STORED IN A PSYCHROPHILIC ANAEROBIC DIGESTER. LIQUIDS TREATED USING A RECYCLING HIGH-RATE TRICKLING FILTER AND POLISHING/RECIRCULATION POND.

Aerobic treatment of the liquid fraction of the waste stream has many advantages such as a high level of odor control and conversion of ammonium nitrogen to nitrate nitrogen. However, the high energy requirements of most extended aeration treatment processes yield them to costly for most animal manure treatment applications. A common low-energy aerobic treatment method is the trickling filter. For swine finishing farms that use a pit-recharge manure handling system the effluent from the settling tank has a BOD concentration that is too high for direct loading on the filter. Therefore, a high-rate filter (50 lb BOD/1,000 ft^3-day) that is loaded after the settling tank effluent is diluted in the polishing/recirculation pond has been specified. The pumps that are used to load the filter are sized so as to provide a recycle ratio of 4 to 6 times the settling tank effluent volume each day. The pond water is also recycled through the barns to remove manure and the liquid level is controlled by land application.

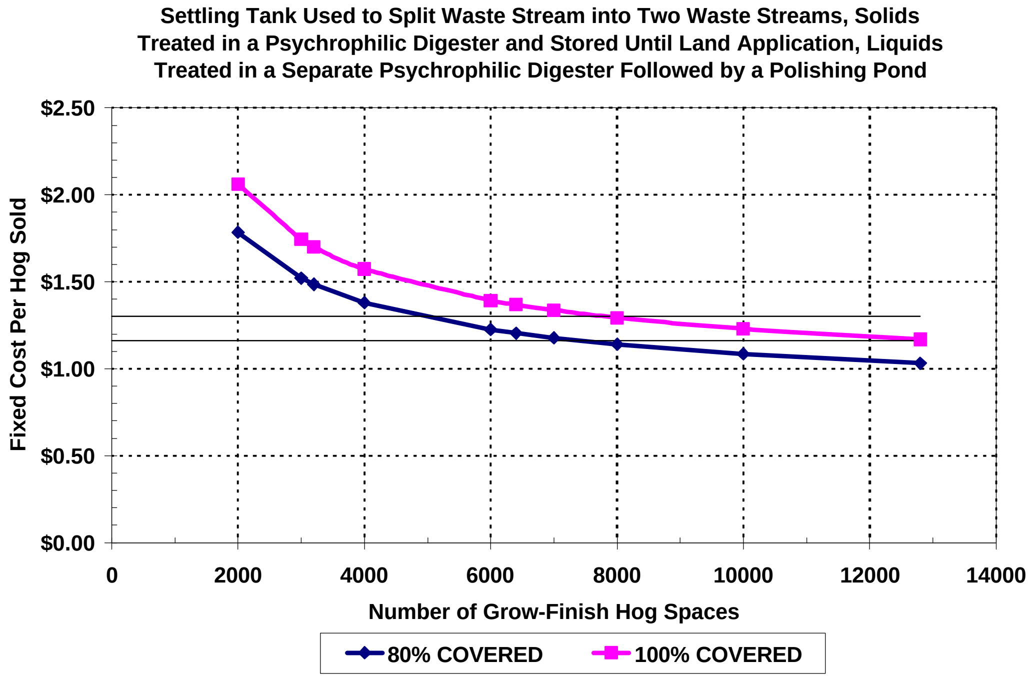

Figure 10. Costs of primary treatment using a settling tank followed by a psychrophilic anaerobic digester for solids (Loading Rate = 25 lb VS/1,000 ft^3-day) and a separate digester and polishing pond for the liquid fraction.

The total cost of this system includes the fixed cost of the containment structures, settling tank, filter media (stone), filter structure, pumps, and filter loading system and the electric cost of the pumps used to load the filter 24 hours/day. The total costs per hog sold are given in Figure 11.

This simple, low-energy aerobic treatment system was not able to meet the cost criterion at any farm size. The main obstacles are the cost of filter media ($14.95/ton) and the energy costs.

Other low-cost aeration systems are being considered that do not require the use of a trickling filter. However, the construction and operating costs are not yet available.

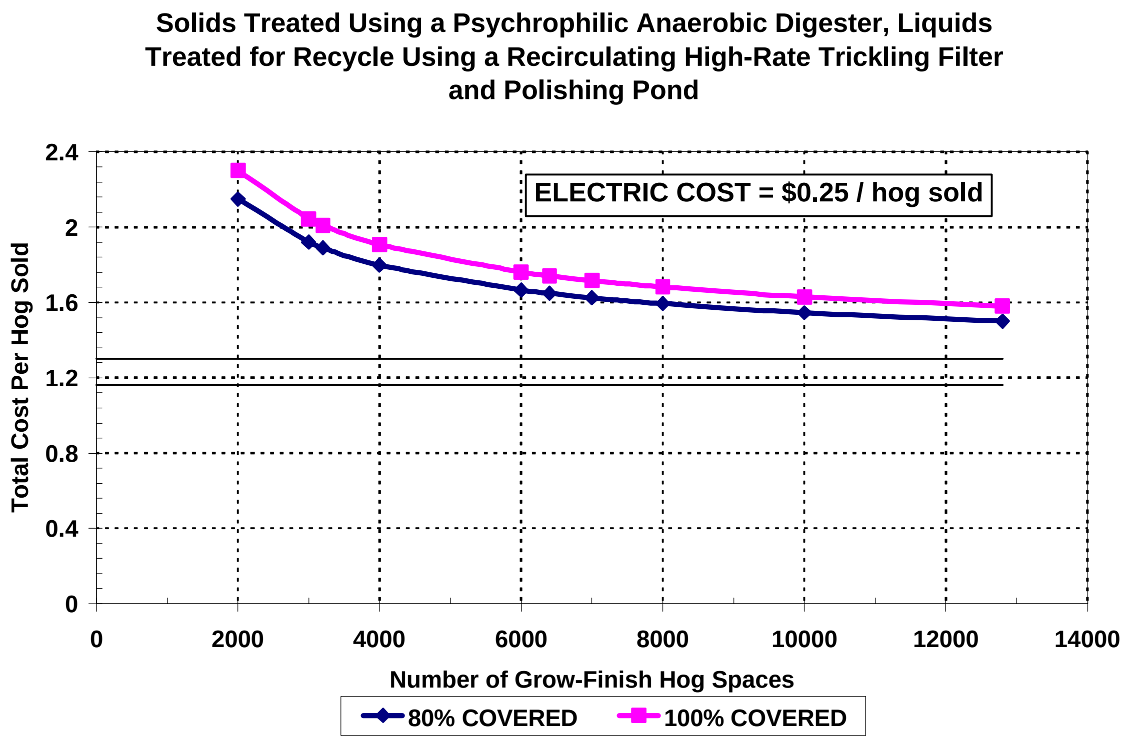

Figure 11. Costs of primary treatment using a settling tank followed by a psychrophilic anaerobic digester for solids (Loading Rate = 25 lb VS/1,000 ft^3-day) and a high-rate trickling filter (50 lb BOD/1,000 ft^3-day, with a recycle ratio of 5) and polishing pond for the liquid fraction. Typical costs for treatment and storage range from $1.16 to $1.30 per hog sold (shown on graph as horizontal lines).

CONCLUSIONS

- The volume and cost of the containment structures required for a particular manure storage and treatment system determined if the system met the defined cost criterion.
- The traditional treatment lagoon is not cost-effective for any size farm or any liner material.
- The only manure treatment and storage systems that met the cost criterion for small farms (3,200 to 4,000 head) were slurry storage ponds, slotted floors over a deep pit, and a geotextile covered storage pond.
- Several systems that utilize anaerobic digestion for treatment and odor control were found to satisfy the cost criterion for farms in the range of 6,400 to 12,800 head of finishing swine.
- The aerobic system that was included was the high-rate trickling filter. The high cost of media and energy costs yielded it too expensive for any farm.

Additional work is needed to define the costs and performance for other aerobic or ozone based systems. Also, the value of manure nutrients and the land investment needed will be included in the future.

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Part V - Conclusion

Conclusion

While significant research has been done and many technologies have been fully developed and tested, not all are so complete. Some have only been researched in laboratory situations. Others have only been used on one or two operations and the full capabilities and limitations of the treatment methods have not been analyzed. However, many alternative treatment methods are available and have been fully developed and researched. These alternative swine manure treatment systems simply await individual commitment and the appropriate funding to allow them to be implemented on a large scale in an actual production facility.

Based upon the information outlined in this report, it is the opinion of the Department Staff, that alternative swine manure treatment technologies do exist for swine facilities of a specific size category. The requirements in the 2001 proposed Reg. 61-43 reflect this decision. These requirements are also supported by the information presented in this report.

Part VI - Acknowledgements

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